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EFFECT OF PLASTIC DEFORMATION AND PHASE TRANSFORMATIONS AT NEGATIVE TEMPERATURES ON THE PROPERTIES OF TITANIUM ALLOYS

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Translation of "Vliyaniye plasticheskoy deformatsii i fazovykh prebrashcheniy pri otritsatel'nykh temperaturakh na svoystva splavov titana," Novyy konstruktsionnyy material -- Titan (A New Construction Material -- Titanium), Edited by I.I. Kornilov and N.G. Boriskina, Moscow, "Nauka" Press, 1972, pp. 104-108.

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16. Abstract

In titanium alloys with an unstable β-solid solution at negative temperatures from -40 to -120°, decomposition of the β-solid solution occurs and deformation martensite is formed. Preliminary plastic deformation by expansion (4%) at negative temperatures of alloys with an unstable β-solid solution reduces the intensity of deformation martensite, and causes a smaller increase of strength properties than cold treatment. Small preliminary plastic deformation of an alloy with a more stable β-solid solution, on the base of an α-solid solution, causes a greater increase of strength properties than ordinary cold treatment.

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EFFECT OF PLASTIC DEFORMATION AND PHASE TRANSFORMATIONS AT NEGATIVE TEMPERATURES ON THE PROPERTIES OF TITANIUM ALLOYS

I.N. Bogachev, M.A. D'yakova, A.K. Bezrukova, and S.I. Selitskaya

In titanium alloys, alloyed with transient elements such as /104* molybdenum and vanadium, the decomposition of the β-solid solution at temperatures above 600° can occur with the formation of the α-phase, in the interval of 500-300° with the formation of the ω-phase and lower than the temperature at which martensitic transformation begins with the formation of α', α"-martensite. The kinetics of the decomposition of a supercooled β-solid solution is determined by the degree and nature of alloying. The decomposition of a supercooled β-solid solution with the formation of α- and ω-phases is described by C-shaped curves [1]. All the transient elements reduce, but oxygen and nitrogen increase the temperature at which martensitic transformation begins. Aluminum, present in transient elements, helps to reduce the temperature at which martensitic transformation begins. Depending on the degree and nature of alloying, an unstable β-solid solution during plastic deformation either decomposes with the formation of an ω-phase [2, 3], or with the formation of martensite [4, 5, 6].

This work investigates the possibility of the decomposition of an unstable β-solid solution when cooled in negative temperatures and the effect of decomposition products on alloy properties. Alloys whose chemical composition is shown in the table were used for research.

The temperature at which martensitic transformation begins in alloys 2 and 3 is slightly above room temperature: in alloy 2, M_H = 50°, in alloy 3, M_H = 65°. To show the effect of plastic deformation on phase transformations and the properties of alloys,

*Numbers in the margin indicate pagination in the foreign text.

CHEMICAL COMPOSITION OF INVESTIGATED ALLOYS.

No. of Alloy	Chemical Composition									
	Al	Mo	V	Fe	Cr	Si	C	H	N	O
1	2.8	7.0	—	0.15	—	0.03	0.03	0.007	0.04	—
2	3.72	7.54	—	0.21	—	0.02	0.04	0.003	0.05	—
3	3.06	5.95	4.47	0.24	—	0.03	0.04	0.012	0.05	0.15
4	4.52	5.85	4.84	1.00	1.10	—	—	—	—	—

an examination was made of the hardening nature of alloy 4, quenched to a β-solid solution; alloy 1, quenched from the two- /105
phase state to an α + β-structure with a β-unstable solid solution; alloy VT1-0 with a polyhedral structure of the α-solid solution. Alloys 2, 3 and 4 were quenched from the β-phase in water. Alloys 2 and 3, after quenching from 920-940°, had a martensitic structure with a residual β-phase and a hardness of 240-250 HB. Alloy 4 was quenched from a temperature of 900° to a β-solid solution structure and a hardness of 300 HB. Alloy 1 was quenched from 800° to a two-phase α + β-structure and a hardness of 300 HB. Alloy VT1-0 was annealed at 650° for 30 min, and had an α-solid solution polyhedral structure and hardness of 200 HB.

The possibility of the formation of martensite at negative temperatures in alloys 2 and 3 was studied by the appearance of a martensitic relief on a polished surface. A sharp relief in these alloys was detected after aging for 15 min at temperatures of -40 and -70°. After alloy 2 had been aged for a month at room temperature, there was an increase of martensitic relief, which shows the isothermal transformation of the residual β-phase into martensite. The formation of martensite during cold treatment significantly affects the properties determined at room temperature. Investigation into the change of mechanical properties of alloys 2 and 3 at room temperature, depending on the temperature of the

preliminary cold treatment (aging at negative temperatures for 15 min, then testing at room temperature) showed that a noticeable amount of isothermal martensite, causing the increase of strength properties, is formed at temperatures of -40 and -70° (Fig. 1, a). At lower temperatures, -120 and -196°, cold treatment does not change the properties. In this case, there is no noticeable amount of isothermal martensite formed which, apparently, is caused by the stabilization of the β-solid solution when aged at this temperature interval. A significant change in the strength properties during cold treatment at -40 and -70° is observed in alloy 2. The yield limit almost doubles -- from 57 kgf/mm^2 in a quenched state to 100 kgf/mm^2 after cold treatment. The yield limit increases from 90 to 120 kgf/mm^2, and the plastic characteristics are somewhat reduced (see Fig. 1, a).

In specimens previously treated by cold at -120 and -196°, martensite deformation occurred during subsequent testing for expansion at room temperature. Preliminary cold treatment in this temperature interval determines the increase of plastic characteristics during subsequent testing for expansion at room temperature.

Research conducted on alloys 2 and 3 in a quenched state, when testing for expansion in negative temperatures, showed that martensitic deformation occurs in these alloys in the expansion process at a temperature interval from 20 to -120°. A reduction of the expansion temperature from 20 to -120° increases the yield limit and ultimate strength while maintaining a great difference between ultimate strength and yield limits (30-40 kgf/mm^2). At an expansion temperature of -196°, when there is no martensitic deformation, the yield limit sharply increases; the difference between the ultimate strength and yield limit is sharply reduced, and the plastic characteristics fall (Fig. 1, c). /106

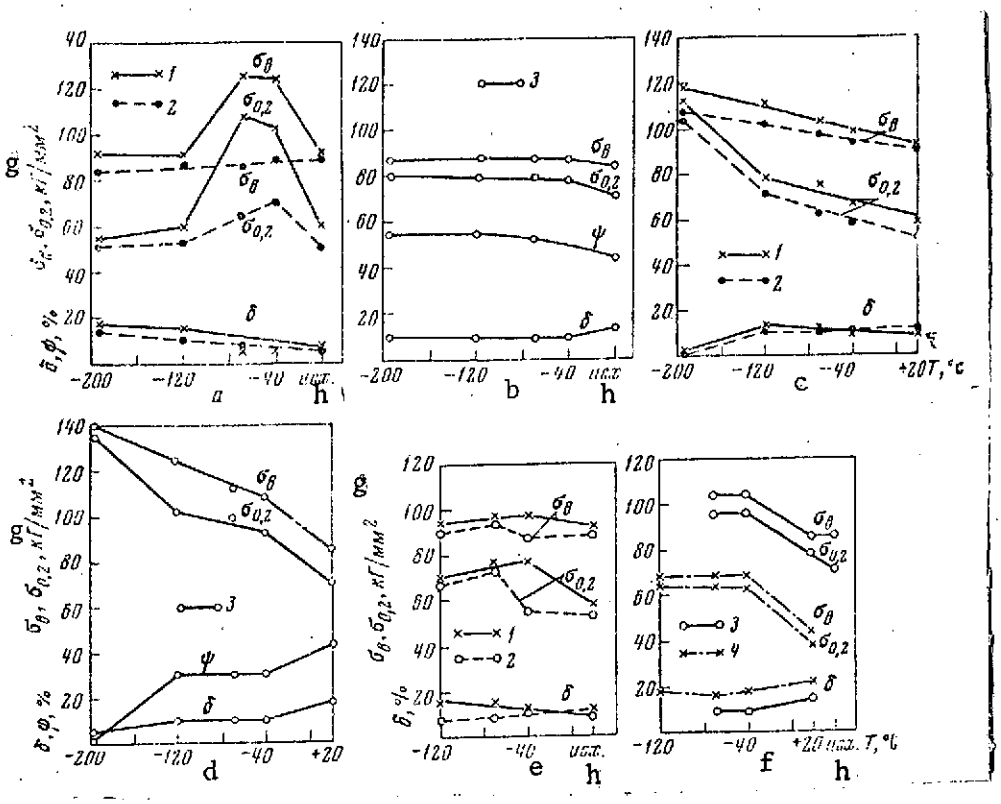

Fig. 1. The effect on the mechanical properties of alloys 2, 3 (a, c, e) and alloy 4, VT1-0 (b, d, f) of the cold treatment temperature, tested at 20° (a, b); the test temperature (c, d) and the preliminary deformation temperature tested at 20° (e, f). Alloy: 1 - 2; 2 - 3; 3 - 4; 4 - VT1-0.

Key: g. kgf/mm^2
h. Initial

Investigation of the change of hardness of quenched alloys 2 and 3, depending on the cold treatment temperature, showed that cold treatment at temperatures of -70 and -40° increases the hardness from 22 HRC, in a quenched state, to 28 HRC, and cold treatment at lower temperatures: -120 and -196° only increases the hardness to 25 HRC. Research into the change of hardness, depending on the temperature of the cooling medium, showed that hardness with a temperature reduction of the cooling medium from 15 to -196° was increased to 30 HRC. The lower the temperature of the cooling medium, the greater the hardness. Phase x-ray analysis showed that α''-martensite is formed as the result of quenching alloys 2 and 3 in different media with a temperature

from 15 to -196° and cold treatment.

Cold treatment at temperatures from -40 to -196° of alloy 4 with a more stable β-solid solution causes a slight increase in yield limit and ultimate strength. Here, the difference between ultimate strength and yield limit is small, 7-8 kgf/mm^2 (Fig. 1, b). When testing quenched alloy 4 for expansion in the temperature /107
interval from 20 to -120°, there was a somewhat greater difference between the ultimate strength and yield limits (15-18 kgf/mm^2) with relatively high values of plastic characteristics. At an expansion temperature of -196°, there is a sharp increase in the yield limit and a reduction of plastic characteristics (Fig. 1, d). The increased difference between the ultimate strength and yield limit in alloy 4, tested at temperatures from 20 to -120°, is caused by the formation of a small amount of martensitic deformation, which is confirmed by metallographic research.

Investigation was also conducted on the effect of plastic deformation by expansion (3-4%) at negative temperatures on the mechanical properties of alloys at room temperature. Results of the research showed that preliminary plastic deformation at temperatures of -40, -70, and -120° of alloys 2 and 3 increases the yield limit, on an average, from 50 to 70 kgf/mm^2 (Fig. 1, e). Information from Fig. 1, a shows that cold treatment at temperatures of -40 and -70°, without preliminary plastic deformation of alloy 2, gives a higher value of yield limits (102-106 kgf/mm^2) and a higher value for ultimate strength (120 against 96 kgf/mm^2, when using a small preliminary plastic deformation). Probably, plastic deformation by expansion (4%) at temperatures of -70 and -120° is rather less than the intensity of the formation of isothermal martensite at these temperatures. Preliminary plastic deformation by expansion (4%) at negative temperatures of -40 and -70° of the higher-alloyed alloy 4 causes an increase of yield limit from 70 to 95 kgf/mm^2 and an increase of ultimate

strength from 85 to 104 kgf/mm^2, compared with the quenched state. Such plastic deformation of this alloy at room temperature hardly increases the strength characteristics (Fig. 1, f). Preliminary plastic deformation by expansion (4%) of the α-alloy VT1-0 at negative temperatures of -40, -70 and -20° causes considerably more hardening, while maintaining plastic characteristics, than deformation at room temperature (Fig. 1, f).

The effect of cold plastic deformation on properties of alloy 1 shows the great strength of alloys with an unstable α-solid solution, decomposing during deformation process with the formation of martensite. Sheets of the alloy of different thicknesses, quenched in water from 800° to a structure consisting of an α-phase and an unstable β-phase, were rolled in a cold state to a thickness of 1.2 mm, at various stages of cold plastic deformation: 5, 15, 30, 50, 70%, then the mechanical properties were determined. At a deformation of 15%, the ultimate strength increases to 140 kgf/mm^2, and at 70%, reaches 160 kgf/mm^2 (Fig. 2, a). The great strength of alloy 1 by cold plastic deformation is caused by deformation and by phase cold hardening when the unstable β-phase is transformed into martensite. The tempering of alloy 1 after plastic deformation at temperatures of 450, 480, 500 and 550° for 18 hours showed that a 5% deformation did not cause the complete decomposition of the unstable β-phase into martensite, and during subsequent tempering at temperatures of 450-550°, the decomposition of the β-solid

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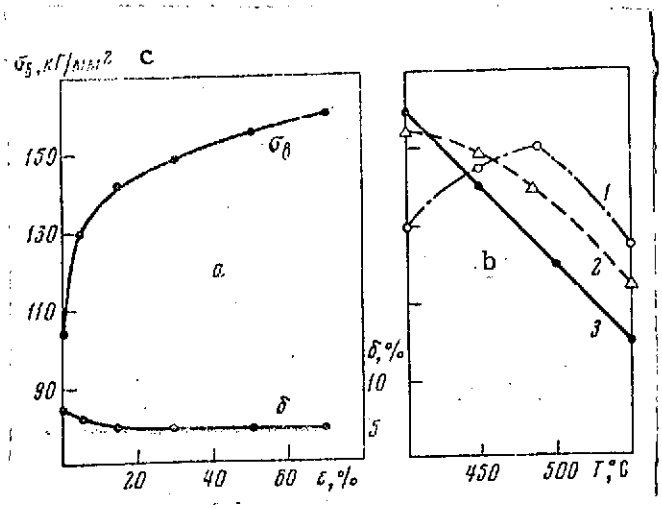

Fig. 2. The effect of the degree of cold deformation ε (a) and tempering temperature (b) on properties of alloy 1.
ε, %: 1 - 5; 2 - 50; 3 - 70.

Key: c. kgf/mm^2

solution was completed by the segregation of a highly dispersed α-phase, which increases the strength properties. Deformation over 15% causes a significant decomposition of the β-solid solution with the formation of martensite, and during subsequent tempering, there is a reduction in the strength properties of the alloy, which is caused by tempering processes of martensite and the removal of cold hardening (Fig. 2, b).

Conclusions

1. In titanium alloys with a temperature where martensitic transformation ends, lower than room temperature, cold treatment at temperatures of -40 and -70° causes the decomposition of the β-phase with the formation of isothermal martensite, and this can cause a considerable increase in strength properties.

2. In titanium alloys with an unstable β-solid solution, during the expansion process at negative temperatures from -40 to -120°, there is a decomposition of the β-solid solution with the formation of deformation martensite, which causes high plasticity, additional hardening due to phase cold hardening, and a large difference between ultimate strength and yield limit.

3. At negative temperatures, preliminary plastic deformation by expansion (4%) of alloys with an unstable β-solid solution reduces, to some extent, the intensity of the formation of isothermal martensite, and causes a smaller increase in strength properties than cold treatment.

4. At negative temperatures, a small preliminary plastic deformation of an alloy with a more stable β-solid solution and an alloy on an α-solid solution base causes a greater increase in strength properties than simple cold treatment.

5. The considerable hardening of alloys with an unstable β-solid solution, with a large amount of plastic deformation, is explained both by deformation and phase cold hardening as the result of the formation of deformation martensite.

REFERENCES

1. D'yakova, M.A. and I.N. Bogachev, in the collection Titanovyye splavy dlya novoy tekhniki [Titanium alloys for new equipment], "Nauka" Press, 1968, p. 131.

2. Gridnev, V.N. et al., in the collection Voprosy fiziki metallov i metallovedeniya [Questions on the physics of metals and physical metallurgy], Vol. 10, Academy of Sciences of the Ukrainian Soviet Socialist Republic Press, 1959, p. 77.

3. Bogachev, I.N. et al., Fiz. Metal. Metalloved. 11/4, 557 (1961).

4. Zwiker, U., Z. Metallkunde 50/5, 261 (1959).

5. Adachi, Masao and Toxuzo Tsujimoto, J. Japan Inst. Metals 25/9, 568 (1961).

6. Holden, F.C., H.R. Ogden, and R.I. Jaffe, J. Metals 8/10, 1388 (1956).